Science Professional Development for the 21st Century

New strategies to transform your PD

By Cindy Hoisington and Jeff Winokur

A *Framework for K–12 Science Education* makes it clear that to improve students' science learning, we must do a better job of preparing and supporting science teachers (NRC 2012). This is not a new appeal. In 1996, the National Research Council (NRC) challenged school systems and policy makers to provide professional development (PD) that would help teachers embrace inquiry-based science teaching and apply newly adopted national science standards (NRC 1996). As we advance in the 21st century, the need to rethink and reframe our approach to science PD has never been greater.

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Building provides opportunities to integrate academic vocabulary.

PD should be transformative. It should shake up teachers' current beliefs and practices; challenge them to think about content and children in new ways; and provide time, space, and support for them to investigate and reflect on new teaching approaches and strategies (Darling-Hammond, Hyler, and Gardner 2017). The report "Not So Elementary: Primary School Teacher Quality in High-Performing Systems" (2016) best reflects this approach. This report analyzed elementary teacher training programs in Japan, Finland, Hong Kong, and Shanghai, finding that PD programs in these high-performing systems address three essential components of pedagogical content knowledge (PCK). All of these programs promote:

- *Teachers' deep knowledge of the science concepts they will teach to students.*
- *Teachers' knowledge of students' thinking and ways to uncover it.*
- *Teachers' knowledge of content-specific teaching strategies that are responsive to how students learn.*

Based on our experience, the first two types of knowledge are foundational to the third. To know which strategies to use and how to apply them, teachers first need to understand science and their students' thinking. For that reason, this article focuses on how we promoted teachers' learning in relation to the first two types of knowledge during the kindergarten PD of *Literacy and Academic Success for English Learners through Science* (LASErS), an i3 project funded by the U.S. Department of Education. Module 1 of the kindergarten PD consists of four full-day face-to-face sessions and focuses on the physical science topic of Building Structures, which aligns with the *Next Generation Science Standards* kindergarten standards in physical science (K-PS2 Motion and Stability: Forces and Interactions) and engineering design. Teachers receive classroom materials for implementing the explorations in their classrooms, including three different types of blocks (foam units, wooden cubes, and Kaplas) and children's books about building (*I Fall Down* by Vicki Cobb; *13 Buildings Children Should Know* by Annette Roeder; and *How a House is Built* by Gail Gibbons).

This challenge to build enclosures was tackled with enthusiasm.

Component 1: Becoming Knowledgeable of Basic Science Concepts

To teach physical science, kindergarten teachers need a thorough understanding of basic concepts (properties of solids and liquids; that multiple forces act on an object). They also need to know the level at which their students will understand these concepts. Otherwise, teachers risk covering basic concepts superficially, trying to explain concepts at a level beyond the reach of kindergarten students, or teaching facts (e.g., Newton's laws) out of context.

Exploring Science Phenomena as Adults

When teachers authentically engage in active, minds-on, adult investigations, they experience physical science phenomena, science and engineering practices, and the nature of science in a way that is not possible with other PD methods (e.g., reading or hearing about concepts or simply reviewing the science activities they will implement with students). In Building Structures, teachers investigate:

- properties of solids (e.g., flexibility, hardness) and forces (e.g., gravity, compression, friction) as they build structures using a variety of blocks (Session 1). Working in collaborative teams, participants build structures of their choice using different types of wooden, foam, cardboard, and sponge blocks. Some groups build one complex structure while others build farms, carnivals, or trains with each participant responsible for one part of the overall structure. In the process, they investigate how material properties (e.g., flexibility, hardness); object properties such as size, weight, shape, and texture; and relevant forces affect whether their structure's stand or topple.

- the impact of design on a structure's stability as they address an engineering challenge to build tall, stable towers (Sessions 2 and 3). In Session 2, each team of participants uses one type of block to investigate how the properties of the blocks, as well as the designs they create, contribute to the construction of a tall tower. Teams reflect on the strengths and weaknesses of their original designs, and in Session 3, they select two to three types of blocks and modify their tower designs aiming for strength and stability as well as height. They measure how strong and stable their towers are by testing them with a fan acting as wind. In addition, participants explore building cantilevers (beams that are

TABLE 1.

Connecting *NGSS* to teachers' explorations.

Component Idea	**Connection to Professional Development Activity** *Teachers:*
PS1.A: Structure and Properties of Matter	• describe and explore different kinds of building materials. • explore how different materials are suitable for different structures and designs. • explore how many structures can be built from a set of pieces.
PS2.A: Forces and Motion	• explore how various forces, including gravity, friction, compression, and tension, act on building materials.
PS2.C: Stability and Instability in Physical Systems	• investigate how multiple forces can either result in a balance of forces (a stable structure) or an imbalance (a structure that topples).
Science and Engineering Practices	
Asking Questions and Defining Problems Planning and Carrying Out Investigations Constructing Explanations and Designing Solutions Engaging in Argument From Evidence	• explore ways to make structures taller. • plan and build stable structures. • describe the characteristics of different building materials. • compare various designs for stability.
Crosscutting Concepts	
Structure and Function Stability and Change	• explore how characteristics of building materials affect a structure. • explore how some structures remain stable while others do not.

unsupported on one end) and the popular game Jenga to learn more about structural engineering.

- form and function as they build enclosures for different purposes (Session 4). In this session, participants are challenged to use one type of building material to create a structure with interior space for an animal or doll of certain dimensions, or a garage for a certain number of toy cars. In this case, participants must consider how to create walls, windows, a door, and a roof that will span the interior space. This experience encourages them to use what they learned in Sessions 1–3 about the properties of the different building materials and design features that contribute to strength and stability as they address new building challenges. It also involves new learning as they explore additional ways blocks can be used in different parts of an enclosure.

Suggestions for engaging children in each of the investigations outlined above can be found in the book *Building Structures With Young Children* (see Resources section for more details).

These concepts connect to physical science core ideas, science and engineering practices, and crosscutting concepts of the *NGSS* for K and elementary (see Table 1). As instructors circulate among groups of adult explorers, we ask questions and make comments that connect teachers to the concepts such as "Where do you think your tower is the most wobbly?" and "How do you think changing the direction of those blocks will make your structure stronger?"

Instructors facilitate follow-up science talks that help teachers make connections between the phenomena they observed (e.g., *foam blocks seem to "stick" together*) and the relevant concepts (*friction*). Group discussion promotes teachers' own thinking about *how* material properties and forces influence their structures. During Sessions 2 and 3, teachers express ideas such as *rigid foam works well at the bottom of the structure because it's solid and rough*; *overlapping the blocks in each layer of the structure creates stability*; and *a wider base on a structure disperses the weight of the load above*.

Investigating Children's Conceptual Understanding

We often observe teachers trying to explain science information, facts, and even broad concepts (e.g., *force*) to children in single activities and trying to teach science vocabulary (e.g., the word *force*) from books or other sources. Thus, we communicate the idea that learning physical

TABLE 2.

A physicist's and a kindergartner's explanations.

Phenomenon	Concept as a physicist might describe it	How a student might begin to understand and express the concept
A structure that can stand without tipping or falling over.	A number of forces influence the stability and strength of structures. Gravity, the most visible, can act on a building in many ways, such as by acting on a building's elements through tension and compression.	Shows awareness that not all buildings will stay up and uses selection of materials and design elements to attempt to stabilize and strengthen a structure.
A structure that includes obvious design elements to achieve balance and/or is able to create internal space.	Successful structural design requires the creation of balanced forces for building up (towers) and for building out (enclosures).	Intentionally works to achieve balance while building. This can be seen in the care taken to place each block in a way that tries to keep the building strong.

science concepts and making sense of the vocabulary requires many direct experiences with objects and materials and opportunities to hear, use, and experiment with related words in context. Together with teachers, we construct a continuum that shows the different ways a physicist and a child might make sense of their observations as well as the different words they might use to express their understanding (see Table 2).

We help teachers construct lists of challenging, academic, and high-use words (e.g., construction, enclosure, material, characteristics) that can be introduced and used in the context of children's building explorations as well as in other settings and situations (see Table 3). We try to help teachers move beyond focusing on science-specific vocabulary that does not support children's everyday oral language and literacy skills (e.g., gravity, hypothesis, rectangular prism).

We also help teachers understand which science concepts are accessible to kindergarten students by introducing the *Framework*'s Grade Band Endpoints for Grade 2 rather than limiting them to the *NGSS* Kindergarten standards. This helps teachers realize that they can take advantage of children's explorations to introduce physical science concepts (such as Structure and Properties of Matter) that are not listed in the kindergarten standards but are clearly appropriate for kindergarten students.

Component 2: Uncovering Students' Thinking

Uncovering students' thinking at different points in an exploration allows teachers to facilitate inquiry and make purposeful, ongoing instructional decisions that are responsive to, and respectful of, children's cognitive capacities (Duschl, Schweingruber, and Shouse 2007). Further, the process of sharing their thinking enables students to practice their developing language and literacy skills in a meaningful context. Teachers are often so focused on what they want children to learn that they don't take the time to find out what students already think or know. We try to bring children's thinking to light in several ways.

Exploring the Practices

First, we get teachers in touch with their own scientific thinking and how they communicate it. After their building experiences, we ask them to analyze how inquiry, language, and literacy contributed to their learning about structures. In Session 3, for example, teachers shared ideas such as: *I found that drawing what I was thinking about how to make the walls really helped me communicate my ideas to the group* and *Listening to my teammates' talk about why they wanted to use cardboard for the roof really pushed me to think about why I wanted to use the flat wooden blocks*.

Analyzing Classroom Video

The use of authentic classroom video provokes analysis and discussion among teachers about children's scientific thinking. Video protocols (adapted from School Reform Initiative: *www.schoolreforminitiative.org*) structure the analysis into two parts (see Figure 1). First, teachers collect and share data on what children in the video say (using language, their bodies, or facial expressions to com-

TABLE 3.

Academic vocabulary.

Nouns	Describing words	Verbs
Structure, building, tower, skyscraper, enclosure, construction, creation; foundation, base; material, characteristic, design; wood, cardboard, plastic, foam; interior, exterior; problem, solution; size, shape, volume, weight, texture	Wood, cardboard, plastic, foam; rough, smooth; flat, arched; heavy, light; dense; quickly, slowly; forcefully, carefully, gently; into, out of, at the top of, at the bottom of, near, far; accidentally, intentionally	Place, expand, extend, construct, insert, remove, create, attempt, solve; topple, teeter, wobble, collapse, balance, wonder, observe, predict, investigate, explore, describe, document, measure, represent, compare, record, think, know

municate) and how they interact with the exploration materials. In the second part of the conversation, teachers generate and share inferences about children's thinking based on evidence from their direct observations. In a video shown in Session 1, for example, teachers observe and interpret children's nonverbal communication. When the teacher in the video asks "Where will you go if there is a hurricane?" one child places a toy at the center of her structure. Noticing, recording, and interpreting the different ways children in the videos express their ideas prepares teachers to look for verbal and nonverbal evidence of their own students' thinking. It can also help them think about creating opportunities for their students to express their thinking in ways that don't rely on oral language.

FIGURE 1.

Protocol for analyzing video.

Video Clip Analysis: Describe children's actions and language, then make inferences about children's observations, ideas, and questions.

First, review the process (2 minutes)

- This process is grounded in description. It is not evaluative.
- The purpose is to uncover this child's/children's perspective.
- The process is formal; it is done in two rounds, and each round is timed.
- During each round, each person in the group will be asked to share. You are free to pass. Everyone listens carefully.

Round 1: Literal Description (2 minutes)

- What did you observe? Describe what you observed the child/children doing and saying.

Round 2: Interpretation (6 minutes)

- What might the child/children be observing, wondering, or thinking?

Collecting and Evaluating Classroom Documentation

After every session, teachers are asked to make observations of their students during each building exploration and collect specific and detailed documentation (written notes, photos, short videos, and children's drawings) of what their students are doing and saying *without interpreting*. They are asked to bring this documentation to the subsequent session for collaborative analysis. At first, teachers share that children are "taking turns with blocks," "having fun building," and "noticing shapes." After several observation experiences, teachers begin to share information that provides more evidence of thinking and inquiry such as "two children stack large rectangles to make a foundation" and "one child says 'the bottom is strong; it's holding everything up.'" We then introduce the idea of formative assessment and help teachers use this evidence to inform their planning of ongoing building experiences.

Reflecting on Teaching and Learning

We view teaching and learning among instructors and participating teachers as parallel and interactive processes. We model and talk about how we use formative assessment as we invite teachers to reflect on science (*What ideas are you developing about how to make tall strong towers?*); children (*What questions do you think your students have about enclosures?*); and the sessions themselves (*What did you find the most helpful in this session and why?*) In turn, we share our own experiences and ideas about science teaching and learning, how well the PD is working, and the changes we make to it as a result of our own assessment and teacher feedback. This creates a culture that engenders trust, confidence, and collaboration among all participants and lays the groundwork for teachers to learn and adopt science-teaching strategies that reflect a thorough understanding of basic science concepts and how children learn them.

During Session 4, we spend extended time with teachers reflecting on their learning from the Building Structures module. Their collaborative responses to what they had learned about teaching science to elementary children (*Exploration provides many opportunities for elementary students to learn and use new concepts and words and Direct exploration enables elementary students to demonstrate their knowledge as well as talk about it; and Real objects and visuals make a big difference in what children are able to do and understand*) were particularly instrumental in the development of the second module, Exploring Balls and Ramps in Kindergarten.

Conclusion

Despite numerous documents making the case for PD reform from 1996 up to the present, little has changed. We know that given the necessary time, space, and support, it is possible for early childhood and elementary teachers to build their knowledge and skills in teaching science. However, it is important to acknowledge that teachers do not work in a vacuum. Too often, they are saddled with improving their own practices even though their opportunities to do so are influenced by multiple factors. These factors include school cultures that do not prioritize intensive, ongoing PD or literacy-centered curricula that are often difficult to integrate with science. To engage teachers in the type of transformative PD that will enable them to promote 21st-century science learning for their students, teachers, coaches, and school and district administrators must all commit to it wholeheartedly. ■

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Duschl, R.A., H.A. Schweingruber, and A.W. Shouse. 2007. *Taking science to school: Learning and teaching science in grades K–8*. Washington, DC: National Academies Press.

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National Research Council (NRC). 2012. *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

Internet Resources

Roos, D. 5 *Things Jenga Can Teach Us About Structural Engineering*. Retrieved from: *https://science.howstuffworks.com/engineering/structural/5-things-jenga-teaches-structural-engineering.htm*

School Reform Initiative. Protocols for building professional learning communities can be found at the website: *www.schoolreforminitiative.org/protocols*

Children's Books About Building

Cobb, V. 2004. *I fall down*. New York: HarperCollins.

Gibbons, G. 1990. *How a house is built*. New York: Holiday House.

Roeder, A. 2009. *13 buildings children should know*. New York: Prestel

Videos

Chalufour, I. and K. Worth, with R. Moriarty, J. Winokur, and S. Grollman. 2004. Building structures with young children (The Young Scientist Series). St. Paul, MN: Redleaf Press (Complete set with DVD)

Building Materials

Dr. Drew's Discovery Blocks: *www.drdrewsblocks.com*

Foam unit blocks are available at retailers such as Lakeshore and Discount School Supply

Kapla Construction Planks: *www.kaplaus.com*

Wooden unit blocks are available at many retailers such as Lakeshore and Amazon